Effect of knee pain on joint loading in patients with osteoarthritis

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Treatment of patients with osteoarthritis is often directed at relieving pain and restoring function. Pain, however, may serve as a protective mechanism in that patients may decrease their levels of activity or alter the manner in which they perform activities in response to pain. Pain reduction may result in increased loads on the joints during dynamic activities, which may result in more rapid disease progression. Therefore, treatment methods that relieve pain but result in a loss of the protective mechanisms associated with pain may not be beneficial in the long term. This mechanism of decreased pain associated with an overuse of the degenerated joint has been referred to as an "analgesic arthropathy." This article discusses common treatments or interventions used for patients with knee osteoarthritis and their potential effects on pain levels and loads at the knee joint during walking. Understanding the relationship between treatment methods, pain, and the knee joint loads during walking is important because walking is the most frequently performed activity, and the cyclic loads at the knee joint during walking are high. Curr Opin Rheumatol 1999, 11:422–426

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Abbreviations

HTO	high tibial osteotomy
NSAIDs	nonsteroidal anti-inflammatory drugs
OA	osteoarthritis

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Treatment modalities for knee osteoarthritis (OA) are frequently directed at decreasing pain and thereby improving function. Nonsteroidal anti-inflammatory drugs (NSAIDs) and analgesics are designed to reduce pain. Pain, however, may be a protective mechanism that keeps the patient from overloading the degenerative portion of the joint. Pain may cause patients to adapt their manner of walking to protect the osteoarthritic joint. These dynamic adaptations likely result in either reduced loads or increased joint stability. For example, among patients with end-stage hip OA, pain levels were inversely correlated with the peak external hip extension moments during gait [1]. The loss of the pain protective reflex from decreases in pain levels likely results in increased load on the joint. This mechanism of decreased pain from NSAIDs or analgesics associated with an overuse of the degenerated joint is one of the mechanisms associated with an "analgesic arthropathy" [2]. Controversy exists as to whether analgesics or NSAIDs result in accelerated joint degeneration [3–5], from either a loss of the pain protective mechanism or from an effect on cartilage metabolism.

To assess whether excessive joint loading from an "analgesic arthropathy" results in accelerated joint degeneration, a greater understanding of the role of dynamic joint loading in the natural history of knee OA is needed. Few studies have addressed this issue, which is surprising given that two major mechanisms associated with the pathogenesis of OA are 1) increased load across the articular cartilage and 2) alterations in the ability of the articular cartilage to withstand loads [6–10]. *In vivo* animal experiments indicate that impulsive loading and joint instability resulted in bone or cartilage changes commonly associated with OA [11–14]. Severe OA rapidly developed in dogs following a dorsal root ganglionectomy and an anterior cruciate ligament transection [14]. The rapid development of OA was attributed to the increased ground reaction forces, which were 30% higher in these dogs compared with dogs with sham procedures [15]. Moreover, dogs with just an anterior cruciate ligament transection did not walk with increased ground reaction forces and did not show extensive OA changes in the same time period. The increased ground reaction forces and associated OA may have resulted from the impaired ability of the dogs to detect knee instability or pain [7,14]. Evidence that knee joint loads play a role in the development or progression of knee OA is further seen in the consis-

Exhibit A

tently positive relationship among men between jobs involving knee bending and knee OA [16,17], and studies that related obesity to the extent of radiographic worsening of OA in women [18,19].

The loads acting at the knee may have important implications with regard to disease progression and outcome from both surgical and nonsurgical treatments [20,21]. This article summarizes how treatment methods for patients with medial-compartment knee OA relate to changes in both pain levels and dynamic knee joint loads during walking. How these changes in pain levels and dynamic loads may relate to disease progression is then discussed.

Dynamic knee loads during gait

Walking is the most frequently preformed activity, and the loads during this activity are high. Direct measurement of joint loads during walking is not feasible on a large scale in humans because of the invasive nature of the method; however, gait analysis can be used to calculate the external joint-loading parameters that are directly related to the internal joint loads. Estimates of the peak knee forces during walking have ranged from three to seven body weights when predicted by analytic models [22–24] and were similar to those measured *in vivo* (2.3 to 2.5 body weights) in a patient [25]. In addition, the peak force on the medial compartment of the knee is almost 2.5 times that of the lateral compartment [23]. This may account for medial-compartment OA being more prevalent than lateral-compartment OA.

The knee adduction moment has been shown to be a major determinant of not just the total load across the knee joint but also its distribution between the medial and lateral plateaus [23]. Variations in the adduction moment were associated with variations in the distribution of bone between the medial and lateral plateaus [26••]. The higher the adduction moment, the greater the load on the medial plateau relative to that of the lateral plateau and the higher the bone mineral content in the proximal tibia under the medial plateau compared with that under the lateral plateau [26••]. An increased adduction moment may be associated with a higher prevalence of medial compartment OA or a faster rate of disease progression. Therefore, understanding the relationship between pain reduction and changes in the knee adduction moment is particularly relevant to understanding the role of loading in the progression of medial-compartment knee OA.

Pain and dynamic knee loads

Two separate studies demonstrate that pain intensity among patients with knee OA was related to the adduction moment. The first study consisted of 18 patients with radiographic evidence of grade II or III knee OA and a varus deformity who were evaluated before and after the use of an NSAID [27]. Following NSAID use, an improvement was shown in the degree of pain and activity of daily living parameters; however, this pain improvement was accompanied by an increase in the knee-joint loads during walking as seen by the increased external knee adduction and flexion moments. Similar changes in the knee-joint loads were also reported following the use of a pure analgesic agent [28]. Although the knee adduction moment is related to an increased load on the medial compartment, the increased external flexion moment is related to an increased net quadriceps muscle activity. Pain relief may have permitted the quadriceps muscle to generate a larger moment to improve joint stability; however, an increased external flexion moment contributes to an overall increase in knee-joint forces [23]. Some of the increased knee-joint loads in this study were a consequence of faster walking speeds following the use of the NSAIDs. Blin *et al.* [29] also showed that NSAID use among patients with knee OA resulted in significant improvements in degree of knee pain (27%) and walking speeds (18%). Walking at faster speeds results in increased ground reaction forces and external knee moments [30,31].

The second study focused in greater detail on the relationship between pain and knee-joint loads during gait. This study involved patients with knee pain and radiographic evidence of medial compartment OA who were part of a larger group enrolled in a double-blinded study [32••,33]. Patients initially discontinued their NSAIDs or analgesics for 2 weeks. Following the 2-week washout period, they underwent a clinical and gait evaluation. They were then given either an analgesic, NSAID, or placebo, and a second gait and clinical evaluation was repeated 2 weeks later. An inverse relationship was found between level of pain and the external adduction moment. The patients whose pain decreased had a significantly increased adduction moment between the first and second gait evaluations ($P < 0.001$). Conversely, the patients whose pain increased had a decreased adduction moment. In contrast to the previous study relating the use of NSAIDs to increased knee-joint loads, the walking speed of the trials analyzed were not significantly different among the evaluations. This suggests that patients used an additional mechanism besides reductions in walking speeds to dynamically decrease the load on the medial compartment.

Others have shown that the range of stance phase knee flexion was inversely correlated with the intensity of pain in patients with radiographic symptomatic knee OA and rheumatoid arthritis [34]. A decreased knee-flexion angle during midstance, when the knee is loaded, likely results in decreased compressive forces across the knee

joint. Stauffer *et al.* [34] also demonstrated that the rates of vertical loading and peak vertical forces were less in those with symptomatic OA compared with to normal subjects, although Messier *et al.* [35] found no significant differences in these forces when comparing symptomatic knee OA patients with healthy control subjects.

Although studies have demonstrated that symptomatic patients with knee OA have decreased joint loads because of pain [27,28,32••,33,34]. Radin *et al.* [36] inferred that, in the absence of pain, subjects who may be more predisposed to developing knee OA have higher impulsive loads during walking. In this study, the impulsive load at heel strike was examined in two groups of subjects: 1) a "preosteoarthritic" group, consisting of subjects with no radiographic evidence of knee OA who were free of knee pain at the time of testing but had a history of knee pain; and 2) a healthy group, consisting of subjects with no history of knee pain or radiographic evidence of OA [36]. The subjects with a history of knee pain had a higher loading rate at heel strike, a lower maximum knee-flexion angle during stance, and a shorter duration of eccentric quadriceps contraction during stance compared with the healthy subjects. The altered knee angles and quadriceps activations could have resulted in less shock absorption; however, whether OA developed more frequently in the "preosteoarthritic" group compared with that of the normal group remained unknown.

Disease severity and dynamic knee loads

If the knee adduction moment relates to the load on the medial compartment of the knee joint, then one would anticipate that the knee adduction moment would correlate with the severity of medial compartment knee OA. In a cross-sectional study of 54 patients with medial-compartment knee OA, the radiographic severity of the disease was related to the magnitude of the adduction moment during gait [37••]. The knees with more advanced OA, as assessed by the Kellgren and Lawrence grading system (KL 3 or 4), had a significantly higher knee adduction moment than did knees with less-severe OA (KL 0–2) ($P < 0.0001$). Similarly, the joint-space width was significantly correlated (inverse relationship) with the knee adduction moment ($P < 0.003$). The relationship between disease severity and magnitude of the load persisted even after accounting for the confounding effects of pain, age, and gender.

High tibial osteotomy and dynamic knee loads

The findings relating disease severity to the adduction moment were consistent with a prospective study demonstrating that individual variations in the preoperative adduction moment during gait related to the radiographic and clinical outcome from a high tibial osteotomy (HTO) [20,21]. The objective of an HTO is to realign the tibia and femur such that some of the load on the medial arthritic compartment is transferred to the more normal lateral compartment. Twenty-four patients with 3 to 9 years' follow-up were tested with gait analysis before surgery. Surgical candidates with a lower preoperative adduction moment during gait had better long-term radiographic and clinical outcomes than did candidates with a higher preoperative adduction moment during gait.

A separate study demonstrated that the postoperative adduction moment was a better predictor of the postoperative clinical outcome than was the postoperative mechanical axis [38]. In addition, although the preoperative adduction moment was not correlated with the mechanical axis, the postoperative adduction moment was correlated with the postoperative mechanical axis [38]. Preoperatively, pain levels may have confounded the relationship between the mechanical axis and the adduction moment.

Summary

The knee-joint loads during walking and other activities may influence the natural rate of disease progression and surgical [20,21] and nonsurgical treatment outcomes. Of concern is the fact that decreases in pain were associated with an increase in knee-joint forces during walking [27,28,32••,33]. These data were consistent with the idea that decreased pain levels lead to a loss of the pain-protective reflex and result in increased joint loads. Whether these increased loads from decreased pain levels lead to an accelerated rate of degeneration or an "analgesic arthropathy" is yet to be determined.

Currently, interventions aimed at reducing the knee-joint loads are rare and focus primarily on weight loss and HTO. Weight loss reduces the axial forces on the knee and has been shown to result in a decreased risk for symptomatic OA [18]. If decreased joint loads are associated with a decrease in prevalence or disease progression of medial-compartment knee OA, then specific interventions need to be developed to decrease the load on the medial compartment of the knee joint. Toe-out angle has been related to the magnitude of the adduction moment [21,39]. Interventions such as gait retraining to increase toe-out angle or foot orthoses that increase toe-out angle may be beneficial for decreasing the adduction moment. In patients with medial-compartment knee OA, gait retraining may achieve a reduction in the dynamic load and thereby have a disease-modifying effect. Gait retraining has been shown to be effective among patients with long-term injuries to the posterolateral structures of the knee and who walk with excessive knee hyperextension [40].

Ideally, then, clinical interventions need to provide pain relief without an increase in joint load. Given that several studies indicate that joint loads were increased following pain relief [27,28,32••,33], care should be taken in the use of pharmaceuticals directed at reducing pain because a reduction in pain seems to be directly related to increased loading of the degenerative portions of the joints. Some investigators have suggested that changes in loading parameters may be different based on the class of analgesic agents or even among the different NSAIDs or that a threshold for drug concentration that allows for an analgesic effect without adversely altering the knee-joint loading may exist [28]. Long-term prospective studies are still needed to evaluate these issues and definitively determine whether increased loading during walking resulting from decreased pain caused by NSAIDs or analgesics results in accelerated disease progression.

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • Of special interest
- •• Of outstanding interest

1 Hurwitz DE, Hulet CH, Andriacchi TP, Rosenberg AG, Galante JO: Gait compensations in patients with osteoarthritis of the hip and their relationship to pain and passive hip motion. J Orthop Res 1997, 15:629–635.

2 Brandt KD: Should nonsteroidal anti-inflammatory drugs be used to treat osteoarthritis? Rheum Dis Clin North Am 1993, 19:29–44.

3 Doherty M, Holt M, MacMillan P, Watt I, Dieppe P: A reappraisal of "analgesic hip." Ann Rheum Dis 1986, 45:272–276.

4 Doherty M: Chondroprotection by non-steroidal anti-inflammatory drugs. Ann Rheum Dis 1989, 48:619–621.

5 Rashad S, Hemingway A, Rainsford K, Revell P, Low F, Walker F: Effect of Non-steroidal anti-inflammatory drugs on the course of osteoarthritis. Lancet 1989, 519–522.

6 Mow VC, Setton LA, Guilak F, Ratcliffe A: Mechanical factors in articular cartilage and their role in osteoarthritis. In Osteoarthritic Disorders. Edited by Kuettner KE, Goldberg VM. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1995:147–173.

7 O'Connor BL, Brandt KD. Neurogenic factors in the etiopathogenesis of osteoarthritis. Rheum Dis Clin North Am 1993, 19:581–605.

8 Radin EL, Schaffler M, Gibson G, Tashman S: Osteoarthrosis as the result of repetitive trauma. In Osteoarthritic Disorders. Edited by Kuettner KE, Goldberg VM. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1995, 197–203

9 Kuettner KE, Goldberg VM: Introduction. In Osteoarthritic Disorders. Edited by Kuettner KE, Goldberg VM. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1995:xxi–xxv.

10 Pelletier JP, Martel-Pelletier J, Howell DS: Etiopathogenesis of osteoarthritis. In Arthritis and Allied Conditions: A Textbook of Rheumatology. Edited by Koopman WJ. Baltimore: Williams & Wilkins; 1997:1969–1984.

11 Lukoschek M, Schaffler MB, Burr DB, Boyd RD, Radin EL: Synovial membrane and cartilage changes in experimental osteoarthrosis. J Orthop Res 1988, 6:475–492

12 Pap G, Eberhardt, R, Sturmer I, Machner A, Schwarzberg H, Roessner A, Neumann W: Development of osteoarthritis in the knee joints of Wistar rats after strenuous running exercise in a running wheel by intracranial self-stimulation. Pathol Res Pract 1998, 194:41–47

13 Radin EL, Martin RB, Burr DB, Caterson B, Boyd RD, Goodwin C: Effects of Mechanical loading on the tissues of the rabbit knee. J Orthop Res 1984, 2:221–234.

14 O'Connor BL, Visco DM, Brandt KD, Albrecht M, O'Connor AB: Sensory nerves only temporarily protect the unstable canine knee joint from osteoarthritis. Arthritis Rheum 1993, 36:1154–1163.

15 O'Connor BL, Visco DM, Brandt KD: Gait alterations in dogs with unstable knee joints: evidence that the central nervous system is reprogrammed to protect unstable joints [abstract]. Trans Orthop Res Soc 1992, 17:478.

16 Andersson JJ, Felson DT: Factors associated with osteoarthritis of the knee in the first National Health and Nutrition Examination Survey (NHANESI): Evidence for an association with overweight, race and physical demands of work. Am J Epidemiol 1988, 128:179–189.

17 Felson DT, Hannan MT, Naimark A, et al: Occupational physical demands, knee bending, and knee osteoarthritis: results from the Framingham Study. J Rheumatol 1991, 118:1587–1592.

18 Felson DT, Zhang Y, Anthony JM, Naimark A, Anderson JJ: Weight loss reduces the risk for symptomatic knee osteoarthritis in women: the Framingham study. Ann Intern Med 1992, 116:535–539.

19 Spector TD, Hart DJ, Doyle DV: Incidence and progression of osteoarthritis in women with unilateral knee disease in the general population: the effect of obesity. Ann Rheum Dis 1994, 53:565–568.

20 Prodromos CC, Andriacchi TP, Galante JO: A relationship between gait and clinical changes following high tibial osteotomy. J Bone Joint Surg Am 1985, 67:1188–1194.

21 Wang JW, Kuo KN, Andriacchi TP, Galante JO: The influence of walking mechanics and time on the results of proximal tibial osteotomy. J Bone Joint Surg Am 1990, 72:905–909.

22 Morrison JB: The mechanics of the knee joint in relation to normal walking. J Biomech 1970, 3:51–61.

23 Schipplein OD, Andriacchi TP: Interaction between active and passive knee stabilizers during level walking. J Orthop Res 1991, 9:113–119.

24 Seireg A, Arvikar RJ: The prediction of muscular load sharing and joint forces in the lower extremities during walking. J Biomech 1975, 8:89–102.

25 Taylor SJ, Walker PS, Cannon PJ, Woldege R: The forces in the distal femur and knee during different activities measured by telemetry. Transactions 43rd Annual ORS Meeting 1997; 259.

26 •• Hurwitz DE, Sumner DR, Andriacchi TP, Sugar DA: Dynamic knee loads during gait predict proximal tibial bone distribution. J Biomech 1998, 31:423–430.

This article shows that the adduction moment, a primary determinant of the medial-to-lateral load distribution, is related to the medial-to-lateral bone distribution of the proximal tibia.

27 Schnitzer TJ, Popovich JM, Anderson GBJ, Andriacchi TP: Effect of piroxicam on gait in patients with osteoarthritis of the knee. Arthritis Rheum 1993, 36:1207–1213.

28 Schnitzer TJ, Andriacchi TP, Fedder D, Lindeman M: Effect of NSAIDs on knee loading in patients with osteoarthritis [abstract]. Arthritis Rheum 1990 [suppl], 33:92.

29 Blin O, Pailhous J, Lafforgue P, Serratice G: Quantitative analysis of walking in patients with knee osteoarthritis: a method of assessing the effectiveness of non-steriodal anti-inflammatory treatment. Ann Rheum Dis 1990, 49:990–993.

30 Andriacchi TP, Ogle JA, Galante JO: Walking speed as a basis for normal and abnormal gait measurements. J Biomech 1977, 10:261–266.

31 Andriacchi TP, Strickland AB: Lower limb kinetics applied to the study of normal and abnormal walking. In Biomechanics of Normal and Pathological Human Articulating Joints. NATO ASI Series, Series E: No. 93. Edited by Berme N, Engin AE, Correia Da Silva KM, 1985:83–102.

32 •• Hurwitz D, Sum J, Andriacchi TP, Schnitzer, TJ, Andersson G: The effects of osteoarthritic knee pain on joint loading [abstract]. Orthop Res Soc Trans 1997, 22:723.

This abstract shows that pain reduction in patients with medial compartment OA is associated with an increase in the knee adduction moment.

33 Sum J, Hurwitz DE, Janik RC, Dressander J, Andriacchi TP, Schnitzer TJ, Andersson GBJ: The impact of osteoarthritic knee pain on dynamic loads during gait. Gait and Posture 1997, 5:173.

34 Stauffer, RN, Chao EY, Gyory AN: Biomechanical gait analysis of the diseased knee joint. Clin Orthop 1997, 126:246–255.

35 Messier SP, Loeser RF, Hoover JL, Semble EL, Wise CM: Osteoarthritis of the knee: effects on gait, strength and flexibility. Arch Phys Med Rehabil 1992, 73:29–36.

36 Radin EL, Yang KH, Riegger C, Kish VL, O'Connor JJ: Relationship between lower limb dynamics and knee joint pain. J Orthop Res 1991, 9:398–405.

37 •• Sharma L, Hurwitz DE, Thonar EJMA, Sum JA, Lenz ME, Dunlop DD, et al.: Knee adduction moment, serum hyaluronic acid level, and disease severity in medial tibiofemoral osteoarthritis. Arthritis Rheum 1998, 41:1233–1240.
This article shows that the extent of disease severity is related to the magnitude of the knee adduction moment during walking.

38 Bryan JM, Hurwitz DE, Bach BR, Bittar T, Andriacchi TP: A predictive model of our come in high tibial osteotomy. Trans Orthop Res Soc 1997, 718.

39 Andrews M, Noyes FR, Hewett TE, Andriacchi TP: Lower limb alignment and foot angle are related to stance phase knee adduction in normal subjects: a critical analysis of the reliability of gait analysis data. J Orthop Res 1996, 14:289–295.

40 Noyes FR, Dunworth LA, Andriacchi TP, Andrews M, Hewett T: Knee hyperextension gait abnormalities in unstable knees: Recognition and preoperative gait retraining. Am J Sports Med 1996, 24:35–45.